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A look at geology, metallurgy, and exploration through the ages...

Short history of man and gold

By

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Some 146 kt (4.69 billion oz) of gold have been mined throughout history. Of this, 70% has been mined in this century alone, with 17% produced from 1985 through 1996 (Fig. 1 and Table 1).

Until the mid-19th century, placers were the chief source of gold. Advancements in mining, metallurgy and geological thinking have resulted in underground mining (first of veins plus stockworks and later of Rand-type deposits) becoming the principal source of gold. With the demise of the South African deposits and the move towards lower grade ores, the primary source of gold will be from disseminated deposits exploited through large, open-pit mines.

For the past 200 years, there has been a fairly constant ratio of about 31 g (1 oz) of gold to each person alive. If this ratio is to be maintained, annual gold production will have to rise from about 2.3 kt/a (73.9 million oz/year) to more than 3.1 kt/a (99.7 million oz/year) by the year 2000. To effect this increase, an unforeseen breakthrough in exploration or metallurgy is needed. Barring this, there will be pressure for an increase in the price of gold.

This article traces the historical production of gold from 4000 B.C. — the earliest record of gold mining — to today and relates this 6,000-year record to advances in geological thinking, mining engineering and extractive metallurgy. It also proposes that man's thirst for gold, reflected in the price he will pay for gold, and his ability to find, mine and refine gold have combined to effect an equilibrium based loosely on the historical ratio of 31 g (1 oz) of cumulative gold production per each man or woman alive.

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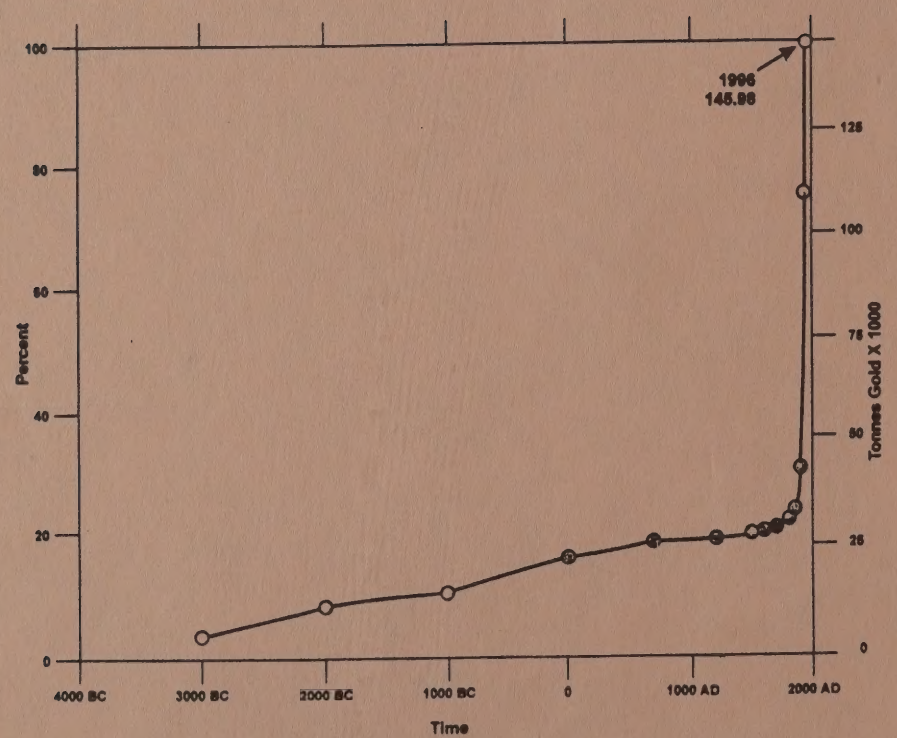
History

Pre-4000 B.C. Man's use and knowledge of metals dates far back into antiquity. Bateman (1950) notes that copper was used by primitive man about 18000 B.C. by which time gold had already been recognized. There is, however, no indication that gold was actively sought or mined until shortly before 4000 B.C. A study by Mohide (1981) cites the discovery in 1972 of the world's oldest treasure of gold. The treasure, unearthed near Varra, Bulgaria on the coast of the Black Sea, consisted of 2,000 solid gold pieces with a combined weight of 5.5 kg (177 oz). The gold was probably mined years previously from surface, or near surface workings in the Transylvanian Alps of Romania. The fact that the gold had been worked into pieces implies knowledge of smelting and metallurgy. This knowledge is also evidenced by the discovery of two 6,000-year-old copper mines, one at Ai Bunar, Bulgaria and the other at Rudna Glava, Yugoslavia. The datings are based on tree ring and radioactive carbon data.

FIG. 1

Cumulative gold production.



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The first gold recovered was undoubtedly of placer origin. Gold nuggets would, by their color and weight, have attracted attention. It would not have taken long for man to use the extraordinary weight of gold (specific gravity 19.3) to assist in concentrating the metal. The first pans, batea or gourds would have been the earliest contribution of the primitive extractive metallurgist. Some ancestral engineer would have developed "booming" to assist in removing gold from the pay gravels. Man also must have recognized fairly early that the source of the gold was upstream and would have "prospected" in that direction. Gold production was considerably less than 1 t/a (32,150 oz/year).

4000 to 2000 B.C. It was just such prospecting that would have led to the discovery of the placers and oxidized residual deposits in upper Egypt and Nubia (Sudan) and the Precambrian quartz vein deposits of what is now Ethiopia. Sutherland (1960) and Forbes (1971) quote early Egyptian sources that describe, in addition to classical placering, extensive underground mining. The tunnels, by 3500 B.C., were up to 5 and 6 km (3 to 3.7 miles) long and as much as 100 m (330 ft) below surface. Early mining engineers carefully surveyed their headings.

To aid in following the ore, the Egyptians used a tubular drill. Using abrasive powders, these forerunners of the diamond drill probably penetrated only 1 m (3.3 ft) or less. But they were used and can be seen today in museums in Egypt. Metallurgy at this time was primitive and gold was recovered principally by crushing and washing.

Gold production from 4000 to 2000 B.C. was on the order of 3 kt (96.4 million oz), or 1.5 t/a (48,220 oz/year). World population was about 15 million people.

2000 to 1000 B.C. In addition to Egypt and Transylvania (Romania/Bulgaria), gold placers were being worked in Ireland, Mesopotamia and China. By 2000 B.C., the prolific placers of Pactolus in Lydia (Turkey) had been discovered (Sutherland, 1960; Forbes, 1971; Boyle, 1979 and Mohide 1981).

Mining techniques also improved. Fire was used to heat rock faces, which cracked when quenched quickly by cold water. As noted by Kavanaugh (1968), production from 4000 to 2000 B.C. was primarily from placer and shallow quartz veining with some minor production from India (probably in the Kolar region) and central Asia.

From 2000 to 1000 B.C. "geological" thinking had recognized the importance of intersecting fissures to bonanzas. Fault displacements were understood and used in the search for gold in the mines of Cassandra in Greece, according to the ancient historian Sagui.

Additional discoveries by prospectors in the Balkans, Russia, Thrace, etc. and such innovations as sheepskin liners in sluices to capture fine gold (hence, the Golden Fleece of mythology) and stepped up output by Egypt combined to produce what would be looked back upon as the Golden Age. The oldest map known, the Turin papyrus dated about 1350 B.C., depicts a mining area, four adits, a well, and the worker's living area (Derry, 1951).

This was also a period in which there were three major advancements in metallurgy. It was known sometime before 1000 B.C. that gold would adhere to mercury through the process now called "amalgamation." Mercury was used to scavenge and collect fine gold from crushed or washed material. The mercury could then be evaporated, or burned off, leaving the gold residue. This process in modernized form is still in use today.

Primitive smelting was known by 4000 B.C. But by 1000 B.C., the art had been developed to include a process known as "liquation." Boyle (1979) describes liquation where, "ores were first smelted often with a siliceous flux to yield an impure ingot. This ingot was then alloyed with lead . . . and the alloy heated to a temperature between the melting point of lead and copper, during which the lead would liquate out carrying the silver and gold with it. The lead was then cupelled to bone ash."

The third major metallurgical discovery during this period was the use of salt (NaCl) to aid in parting gold from silver. This enabled the production of finer gold. Early Egyptian gold is of a whitish, or even speckled, variety due to inclusion of silver, platinum and copper. By 1000 B.C. "purer" gold was being provided.

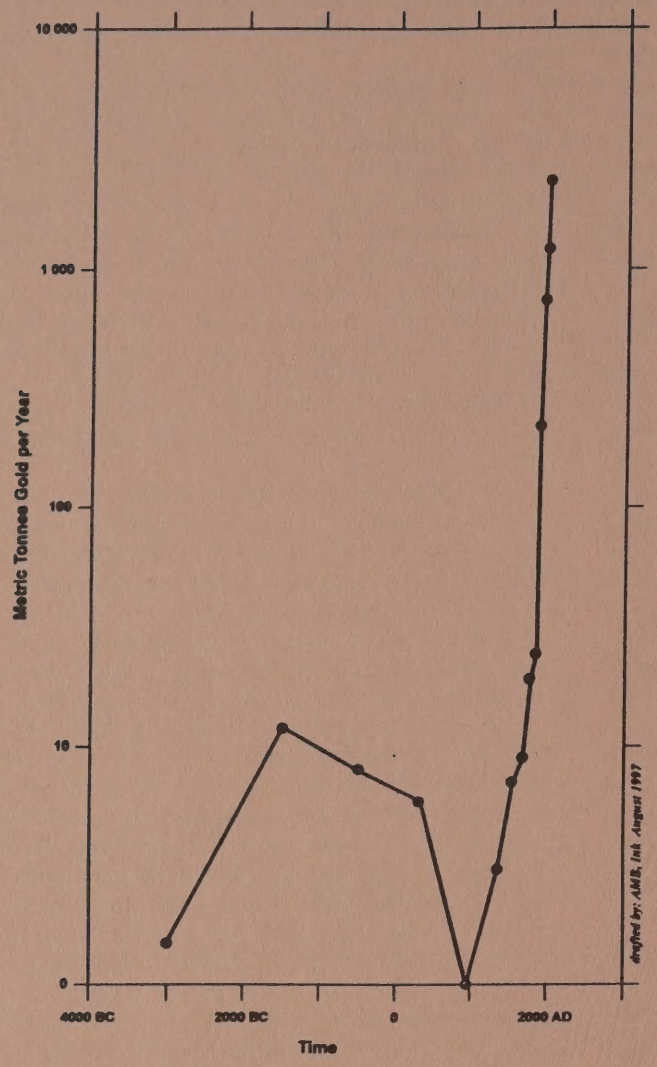
Table 1

World gold production (metric tonnes).

Period	t/a gold	Production (t)	% total	Cumulative	% cumulative
4000-2000 B.C.	1.5	3,000	2.1	3,000	2.1
2000-1000 B.C.	12.0	12,000	8.2	15,000	10.3
1000 B.C.-0	8.0	8,000	5.5	23,000	15.8
0-700	6.0	4,000	2.7	27,000	18.5
700-1200	1.0	500	0.3	27,500	18.8
1201-1493	3.0	1,000	0.7	28,500	19.5
1494-1600	7.0	715	0.5	29,215	20.0
1601-1700	9.0	896	0.6	30,111	20.6
1701-1800	19.0	1,904	1.3	32,015	21.9
1801-1850	24.0	1,212	0.8	33,227	22.8
1851-1900	210.0	10,430	7.1	43,657	30.0
1901-1950	730.0	36,607	25.1	80,264	55.0
1951-1984	1,210.0	41,280	28.3	121,544	83.3
1985-1994	1,989.0	19,886	13.6	141,430	96.9
1995	2,250.0	2,250	1.5	143,680	98.4
1996 (estimated)	2,300.0	2,300	1.6	145,980	100.0

FIG. 2

Gold production rate.



Gold production from 2000 B.C. to 1000 B.C. appears to have been three times that of all previous production. For years, King Solomon reportedly received a tribute of 18 t/a (579,000 oz/year) of gold from subjugate peoples. Annual worldwide production was more than 12 t (385,800 st). World population was 38 million people.

1000 to 700 A.D. The period of plenty ended some decades before the modern era. Nothing could bring gold production to the total of the Golden Age. Not even the geologic acumen of Herodotus, who in 450 B.C. noted the relation of gold to quartz veining, or the engineering skills of the Romans, who used the Archimedes screw to dewater their Spanish mines and who removed by 100 A.D. 30 to 40 Mt (33 to 44 million st) of gold ore from one Iberian mining camp.

Diodorus in the 2nd century B.C. gave a vivid description of underground mining of the period. He describes miners who worked with lamps strapped to their foreheads and young boys who hand carried the ore to the surface.

Pliny (23 to 79 A.D.) described Rome's Spanish mines that produced about 10 t/a (321,000 oz/year) of gold through the first century of the modern era, but from which production dwindled sharply thereafter.

Meanwhile, the great deposits of Ireland, Egypt, Lydia and Georgian Russia had been depleted, or developed to depths below which mining was not feasible.

Gold production dropped to +/-7 t/a (+/-225,000 oz/year), or about half that of the prior millennium. Population increased to 200 million people.

700 to 1500 A.D. By the 8th century A.D., virtually no new gold was being produced in the western world. Known deposits were exhausted. The world's store of gold slowly moved east as payment for goods from and beyond Constantinople (Istanbul). Advancements in gold technology now were also made in the East. Moslem alchemists of the 13th century were the first to use nitric acid to part gold from silver.

Gold became so scarce in Europe that, from the 9th century to the mid-13th century, no gold coins were minted on the continent. The Dark Ages of Europe correspond to the period of lowest gold production, 2 t/a (64,300 oz/year). The world's population increased to 350 million people.

1500 to 1850 A.D. Gold, however, was being mined in Asia and Africa and by the Aztec, Inca and related societies in South and Central America. Using primitive methods, great quantities of gold were amassed by these isolated peoples. Quantities so great that when the Spaniard Pizarro conquered Peru in 1532, the Incan ruler Atahualpa paid his ransom with a roomful of gold estimated to weight about 6 t (193,000 oz).

From 1522-1547, 30 t (964,500 oz) were moved from Mexico to Spain. The sudden influx of South American gold from 1492 to about 1600 represented about 40% of the world's production during that period (Boyle, 1979).

The gold treasure of South America and the discovery and exploitation during the next 300 years of the great placers of Colombia and Brazil provided the wealth that triggered the Renaissance in Europe and the eventual Industrial Revolution. The Industrial Revolution would, in the 19th and 20th centuries, allow for gold mining on a scale undreamed of, even in the Golden Age.

The discovery of the South American gold deposits was not accompanied by any great advancement in mining or metallurgy. Prospecting was successful in the virgin lands of the Americas. However, it was still based primarily on the lessons learned in the placer fields. Mining was still confined to relatively shallow depths.

Mining rates in the Americas, however, rose under the direction of the Spaniards. They placed a much higher value on gold than did the native peoples. The richness of the deposits and the ardor of the Spaniards was such that, whereas world production had been about 2 t/a (64,300 oz/year) from 700 to 1500 A.D., production rose to more than 7 t/a (225,000 oz/year) in the 16th century and to almost 9 t/a (289,300 oz/year) in the 17th century.

In the 18th century, the South American deposits alone produced more than 15 t/a (483,300 oz/year) of gold. However, the pattern was to change in the 19th century due to the major discoveries in the Ural Mountains and Oxus Valley of Russia and smaller, but locally significant, deposits in North America.

Scientific interest in mining, geology and metallurgy increased with the influx of South American gold. Argicola's famed *De Re Metallica*, published in 1556, one

year after his death, reflects the attention of the educated world to the history, methods and problems of mining. This attention may also have exerted some positive force on the increasing production rate.

Gold extraction methods changed, too. For centuries, washing and amalgamation had been the principal means of recovering gold. In the latter part of the 18th century, chlorination came into widespread use. It continued as a prime process until cyanidation methods were developed in the late 19th century (Dorr, 1936).

In chlorination, chlorine gas is passed through wet, crushed ore. The gold combines with the chlorine to form a gold chloride that is removed with water and precipitated by ferrous sulfate. Chemical metallurgy was coming of age.

Gold production increased from 2 to 3 t/a (64,300 to 96,450 oz/year) in the 1400's, to 7 t/a (225,000 oz/year) in the 1500's, 9 t/a (289,300 oz/year) in the 1600's and 19 t/a (610,900 oz/year) in the 1700's. By 1800, the world's population had increased to 700 million people.

Table 2

Gold per capita.

Period	Cumulative gold production*	World population**	Cumulative oz gold per capita
4000-2000 B.C.	96.5	15	6.4
2000-1000 B.C.	482.2	38	12.7
1000 B.C.-0	739.5	100	7.4
0-700	868.1	200	4.3
700-1200	884.1	265	3.3
1201-1493	916.3	360	2.5
1494-1600	939.3	435	2.2
1601-1700	968.1	575	1.7
1701-1800	1,029.3	700	1.5
1801-1850	1,068.2	1,000	1.1
1851-1900	1,403.6	1,400	1.0
1901-1950	2,580.5	2,100	1.2
1951-1984	3,907.6	3,500	1.1
1985-1994	4,547.1	5,700	0.8
1995	4,619.4	5,800	0.8
1996 (estimated)	4,693.4	5,900	0.8
2000 (estimated)		6,300	

*million troy oz.
**in millions.

1850 to 1900 A.D. During the 17th, 18th and 19th centuries, there was a migration of people from Europe to the Americas. Part of the attraction bringing early settlers to North America was that the exploitation of South America yielded vast quantities of gold. Many early accounts tell of North American gold that had been sent back to France, England and Holland, although no major finds had been proven.

In the opening decades of the 19th century, the only gold mining of note in North America was centered in the Carolinas in the southeastern states. Here, mining was concentrated first on placer deposits and later on residual low grade, sulfidic ores.

These workings were virtually abandoned when in 1848, 1849 and into the 1850's when word came of the discovery of free, easily worked gold in California.

The gold discoveries in California started a gold rush unlike any in history. It is estimated that nearly 400,000 men came to seek their fortune in California from 1849 to the mid-1850's.

The 1849 gold rush was unique because for the first time in history, following a major gold discovery no government, state, monarch or ruler declared the deposits to belong to the realm. A man could stake a claim and, if he was fortunate enough to find gold, he could mine it and sell it for his own gain. The challenge and opportunity attracted many.

Because of the sheer number of men who suddenly became "educated" into the "mysteries" of gold, the California gold rush spawned discoveries elsewhere. The dissemination of knowledge on how to pan, prospect and recognize favorable gravels, favorable ledges etc., led to the discovery in 1859 of the great Comstock lode in Nevada.

The Australian E. H. Hargreaves recognized in the California gold fields signs he had seen in his native Australia. He returned there in 1851 to discover gold at New South Wales. This indirectly led to the rush to Ballarat, Victoria. And in 1876, two California prospectors, Moses and Fred Manual, staked what was to become the world famous Homestake gold mine in South Dakota.

The effect of this explosion in exploration increased world gold production eight-fold from the 24 t/a (771,600 stpy) from 1800 to 1850 to more than 200 t/a (6.4 million oz/year) from 1851 to 1900.

The quantum increase was due in part to the success of prospectors in new lands. But it was also due to the introduction and ready dissemination of new ideas, techniques and methods in mining and metallurgy. Steel replaced wood and stone for axes and bars. Explosives replaced fire and water to break rock. Pumps cleared water from workings. Stamp mills driven by steam replaced hand mortars or animal power arrastras.

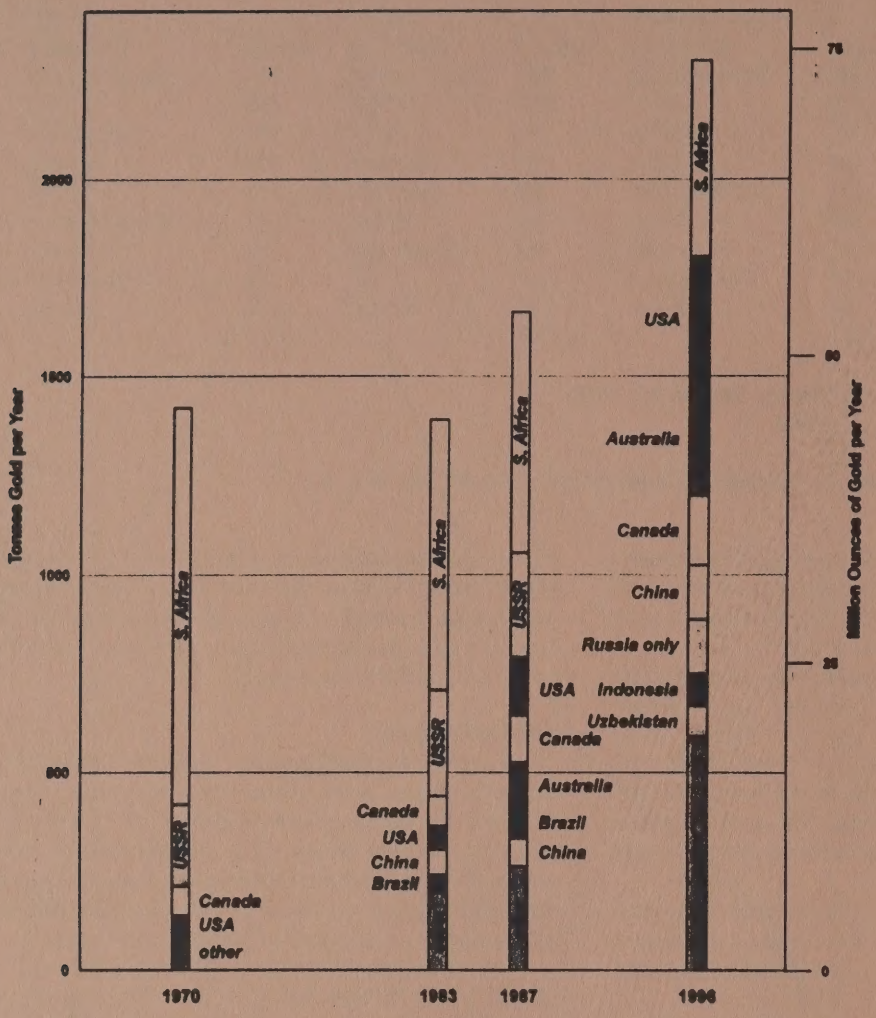
The prospector was aided by the introduction in 1862-1863 of the first diamond drill. It was designed by Swiss engineer Jan Rudolphe Leschot and built by Pichet in Paris, France. The machine was hand operated by two men. In 1867, M. C. Bullock patented a steam-driven drill. Today's drills, powered by air, electricity or petroleum, are an indispensable part of exploration.

The miner's ancient problem of flooding was relieved when steam-driven pumps became widely used in many underground mines. Placed first in the Cornish tin mines, their use spread quickly.

The first of the great US open pits was at Bingham, UT. It was designed and began operation in the 1880s. In 1891, the McArthur Forest cyanidation process was successfully applied to recover gold from refractory ores at the Mercur Mine, also in UT. Recoveries rose from 70% to 95% of contained gold. In cyanidation, gold from finely crushed ores is dissolved into a cyanide solu-

FIG. 4

World mine production of gold — major country rankings.



(578.7 million oz) of gold (about 15%) have been lost, consumed in industrial processes or are otherwise unrecoverable.

DMBW's estimate is about 25 kt (803.7 million oz) higher than this latest US government estimate. It is, however, roughly consistent with a 1986 US government estimate (Thomas and Boyle, 1986).

The effect of having chosen the 121-kt (3.89-billion oz) figure would be that production in this century would represent 85% of cumulative world gold production rather than 70%.

Gold supply and human population

As seen on Fig. 3 and Table 2, cumulative gold production on a per capita basis has not risen. Instead, it has declined steadily to about 10% of what it was about 1000 B.C. The real decline in per capita gold is even more marked than suggested by this data considering losses of gold over the millennia (catastrophic floods, shipwrecks, burials, fires, etc. and, more recently, industrial consumption).

During the past 200 years, there has been about 31 g (1 oz) of cumulative gold — the total in circulation, in vaults, jewelry, etc. divided by the world's population — available for each person in the world.

From 1996 through 200.0 demographers project 400 million more people. To mine an equivalent 12.5 kt (400 million new oz) during the four-year span would require mining of 3.1 kt/a (9.96 million oz/year) of new gold. Such an increase from the present level of 2.3 kt/a (73.9 million oz/year) of gold seems unlikely. This is especially true in the light of the declining production from South Africa and Russia (Table 3 and Fig. 4), as well as the increasing constraints on resource exploitation in the United States and Canada. Therefore, it might be expected the gold per capita figure will drop further by the year 2000. This "shortage" will eventually trigger an increase in demand that may act to raise the price of gold. This hypothesis assumes that the present world population and its +/-1.6% growth rate is neither excessive nor unsustainable. ■

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